Passive Active L/S-band Microwave Aircraft Sensor for Ocean Salinity Measurements

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Abstract – A Passive/Active L/S-band (PALS) microwave aircraft instrument to measure ocean salinity has been built and tested. Because the L-band brightness temperatures associated with salinity changes are expected to be small, it was necessary to build a very sensitive and stable system. This new instrument has dual-frequency, dual polarization radiometer and radar sensors. The antenna is a high beam efficiency conical horn. The PALS instrument was installed on the NCAR C-130 aircraft and salinity measurement missions were flown on July 17-19, 1999, southeast of Norfolk, Virginia over the Gulf Stream. The measurements indicated a clear and repeatable salinity signal during these three days, which was in good agreement with the R/V Cape Hatteras salinity data. Data was also taken in the open ocean and a small decrease of 0.2 K was measured in the brightness temperature, which corresponded to the salinity increase of 0.4 psu measured by the M/V Oleander vessel.

I. INTRODUCTION

Microwave radiometry and scatterometry are well known techniques for surface remote sensing. Combining passive and active sensors provides complementary information contained in the surface emissivity and backscatter signatures, which may improve the accuracy in the retrieval of geophysical parameters. For example, over the ocean, the passive radiometer brightness temperature is a function of the Sea Surface Temperature (SST), the Sea Surface Salinity (SSS) and the surface roughness from wind and waves. Using dual frequencies and dual polarization provides information on the SST, SSS and roughness. However, it has been shown that by adding an active scatterometer, more direct information on the surface roughness is provided, which significantly improves the accuracy of the retrieved SSS [1].

To investigate the benefits of combining passive and active microwave sensors, the Jet Propulsion Laboratory (JPL), with NASA support, has designed, built and tested a new precision Passive/Active L/S-band (PALS) microwave aircraft instrument for measurements of ocean salinity. Because the L-band brightness temperature variations associated with salinity changes are small, e.g. a salinity change of 0.2 psu results in a brightness temperature change of 0.1 K, it was necessary to build a very accurate, sensitive and stable system. After a series of simulations of radiometer and radar measurements [2], the instrument requirements were determined to allow salinity measurements to be made with an accuracy of 0.2 psu over the open ocean. This new instrument has dual-frequency (L- and S-band), dual polarization radiometer and polarimetric radar sensors and was installed in the National Center for Atmospheric Research (NCAR) C-130 aircraft. The antenna is a high beam efficiency conical horn with relatively low sidelobes pointed at a 38° incidence angle to the ocean surface. An IR temperature sensor was used to measure the changes in the sea surface temperature. To achieve maximum radiometer stability a three position Dicke switching scheme was used with a noise diode calibration. The radar electronics calibration was achieved using an internal calibration loop.

II. SYSTEM DESCRIPTION

An overall block diagram of the PALS instrument is shown in Fig. 1, and the key system characteristics are summarized in Table I.

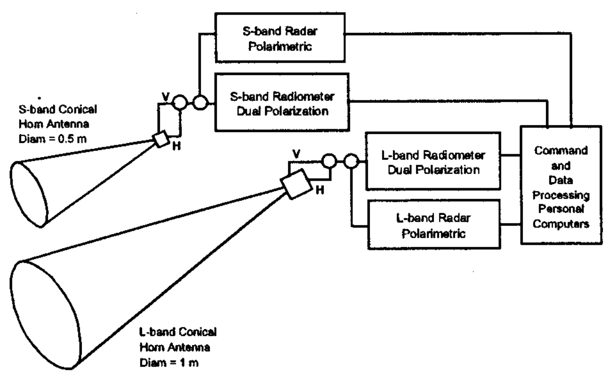

Fig. 1. PALS overall system block diagram showing the separate L and S-band radiometers and radars.

Table 1. PALS System Characteristics

Radiometer Frequencies	1.41 and 2.69 GHz
Radiometer Polarizations	Vert (V) and Hor (H)
Radar Center Frequencies	1.26 and 3.15 GHz
Radar Polarizations	VV, HH, VH
Antenna Type	Conical Horns
Aperture Diameter (L&S)	1.2 and 0.6 m
Antenn Gain and Beam Efficiency	23 dB and > 92%
Antenna Incidence Angle	38°
Antenna Spatial Resolution at 1.3 km altitude	0.5 km
Radiometer Bandwidth (L&S)	20 and 5 MHz
Radiometer NEDT per Footprint (L&S)	0.2 and 0.4 K
Radiometer Absolute Accuracy	1 K
Radar Transmit Power and Duty Cycle	5 Watts and 8%
Radar Noise Equivalent σ_o at 1.2 km altitude	< -45 dB
Radar Calibration Stability	0.1 dB

A number of antenna designs were considered for this precision L/S-band instrument. The basic requirements were to achieve low loss, beam efficiencies > 90%, sidelobes < 20 dB, and cross polarization isolation > 20 dB. It was concluded that with these constraints, the conical horn was the best choice for the antenna to meet these requirements. The L-band antenna has an output diameter of 1.2 m and a length of 3.4 m. A waveguide to coax OrthoMode Transducer (OMT) is attached to the end of the horn to separate the Vertical (V) and Horizontal (H) polarizations. At each frequency, the conical horn antenna is time shared between the radiometer and radar. The system is switched to the radar scatterometer 17% of the time. The system is also switched between the two polarizations so that only one set of radar and radiometer electronics is required for each frequency band.

The two antenna horns were mounted in an aluminum frame and installed on the back ramp of the C-130 aircraft. During the flights, the ramp of the C-130 aircraft was lowered and the frame assembly was raised to the position where the antennas were pointing down to the 38° incidence angle. (The antenna assembly angle can be adjusted to achieve other incidence angles.) A photograph of the raised antenna assembly is shown in Figure 2.

The precision radiometer uses a noise diode injection scheme, along with a three sequence Dicke switching cycle for maximum stability. The dual frequency radar system is a short pulse radar system with a 2.86 kHz Pulse Repetition Frequency (PRF) and an output power of 5 Watts. There is a series of 10 "frequency hops," to get independent radar samples, over a 20 MHz bandwidth. A calibration loop is

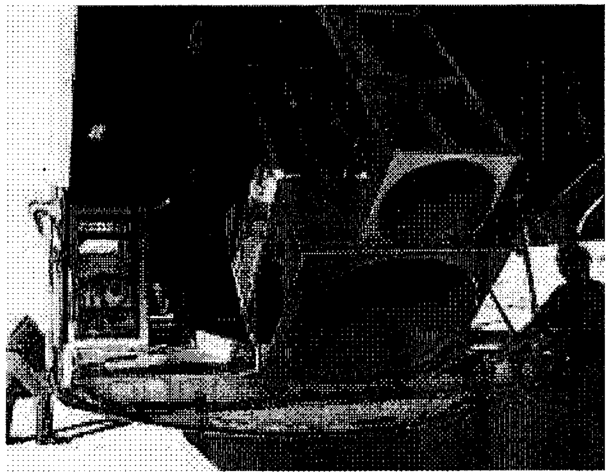

Fig. 2. The L and S-band horn antennas on the rear ramp of the C-130 aircraft raised to the observing position.

used in the radar to couple a small faction of the transmitter power to the receiver to monitor the transmitter power. All the radar Local Oscillator (LO) signals are phase locked to a 10 MHz reference oscillator to provide phase coherence among all the signals. The control and data system for PALS uses three Pentium II based personal computers, networked together to generate all the system timing signals, and processes and record the data. The aircraft attitude and location data was incorporated directly in the radiometer and radar data files.

III. CALIBRATION

During the Atlantic Ocean measurements in July, radiometer measurements were made over the NDBC Buoy 41001. These values were then compared with the predicted temperatures from the model for ocean brightness temperatures by Ellison, et al. [3]. For this case, the Ellison model was run with a Sea Surface Salinity = 36 psu, using the IR temperature of 28 C, and a wind speed of 5 m/s. (The temperature and wind speed were taken from the buoy data and the value of 36 psu was used based on data from the R/V Cape Hatteras.) The predicted temperatures for an incidence angle of 38° were: V = 115.8 K, H = 81.3 K for L-band. (Note that these values include the reflected atmospheric/cosmic background emission and the *in-situ* atmospheric emission of ~4 K.) Using measured antenna loss values, the system calibration values were adjusted to match the predicted ocean temperatures. Based on this calibration procedure, it is estimated that the absolute calibration of the radiometers was within 1 K.

The radar signal is calibrated by measuring the transmitted power through the calibration loop, and then using the measured system losses, antenna gain, and target range to calculate the radar target cross section, σ_o. It is estimated that the values of σ_o have errors ± 2 dB.

IV. TEST FLIGHTS

The PALS instrument was installed on the NCAR C-130 aircraft in May/June 1999. Because of the large size of the antenna horns, this was the most practical aircraft for the PALS instrument. The instrument was mounted with the antenna assembly installed on the rear ramp of the aircraft, which was closed during takeoff and landing. When up to the cruising altitude of ~1.3 km (3,900 ft), the ramp was lowered, and the antenna assembly was raised to have the antennas pointing down at a 38° incidence angle.

Three flights were made for ocean salinity measurements. These were on July 17, 18, and19, 1999, southeast of Norfolk VA, over the Gulf Stream, and out into the open ocean. The surface truth measurements of SSS, SST and surface winds were gathered by Stephan Howden from the R/V Cape Hatteras. The L-band radiometer and radar data from flights on July 18th over the Gulf Stream along with the ship data are shown in Fig. 3.

These data show that the L-band brightness temperature, corrected for surface roughness and temperature, decreased about 3 K in both polarizations when crossing the Gulf Stream. Along this track, the ship data shows an increase of 5 psu in the ocean salinity. The aircraft track and the ship track were separated by ~20 km, which may account for the slight differences in the alignment of the salinity and brightness temperature gradients. The change in the S-band brightness temperature was ~1K, which shows the decrease in SSS sensitivity at the higher frequency. Note that the radar data shows relatively small changes in the surface roughness due to wind, and this roughness effect has been corrected in the radiometer data. At L-band, this correction is small, ~ 0.3 K per 1 m/sec [4]; however, in the open ocean where the salinity signal is small, it is important to correct for the effect to reduce the error. This data has also been corrected for the changes in the SST and has been normalized to a 28 C temperature.

To show the ability of the PALS system to measure small salinity changes, part of the flight path on July 18th covered the track of the M/V Oleander vessel, which had transited the day before. The M/V Oleander is a container cargo ship, which has a NOAA salinity sensor and measures the salinity on its route between Port Elizabeth, NJ and Hamilton, Bermuda every week. The radiometer data over the M/V Oleander track shows an L-band brightness temperature decrease of ~0.2 K. (This value has been corrected by 0.1 K due to the IR temperature increase of 0.7 K.) In this track, the radar backscatter was nearly constant, and thus only small

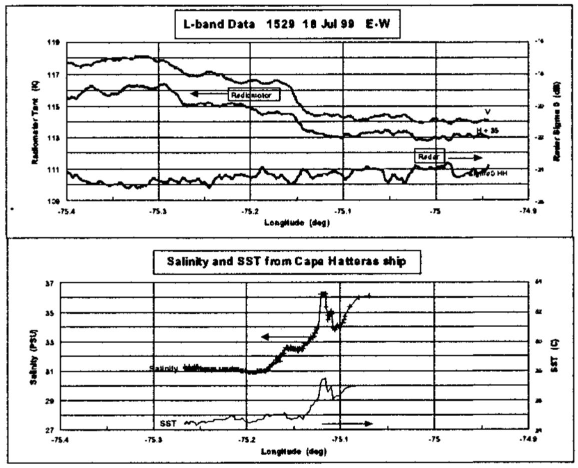

Fig. 3. L-band brightness temperature and ocean salinity data over the Gulf Stream on July 18, 1999. The H polarization radiometer data is offset by +34 K to show both sets of data.

corrections to the radiometer data for surface roughness were required. Over this track, the salinity data measured the day before, increased by 0.4 psu, which is consistent with the decrease in the measured brightness temperature.

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